Chapter 20
Magnetism

20.1 Magnets and Magnetic Fields
Magnets have two ends – poles – called north and south.
Like poles repel; unlike poles attract.

However, if you cut a magnet in half, you don’t get a north pole and a south pole – you get two smaller magnets.

Magnetic fields can be visualized using magnetic field lines, which are always closed loops.

The Earth’s magnetic field is similar to that of a bar magnet.
Note that the Earth’s “North Pole” is really a south magnetic pole, as the north ends of magnets are attracted to it.

A uniform magnetic field is constant in magnitude and direction.

Where is the true north pole? (3:53)
Magnetic Field

• Magnetic Field is a vector field $\vec{B}$
• Units of Magnetic Field: Tesla (T)

20.2 Electric Currents Produce Magnetic Fields

Experiment shows that an electric current produces a magnetic field.

Direction determined using small magnets

Right Hand Rule #1

Drawing 3D Fields

Can represent $B$ field

End
On View
Field Out of Board
Field Into Board

Everywhere inside the coil, field is out of board.
Outside of coil, some into the board and some out of board.
20.2 Electric Currents Produce Magnetic Fields

The direction of the field is given by a right-hand rule.

**Right Hand Rule #2**

20.3 Force on an Electric Current in a Magnetic Field; Definition of B

A magnet exerts a force on a current-carrying wire. The direction of the force is given by a right-hand rule.

**Experimental Observations**

- Force proportional to current in wire
- Force proportional to length of wire in magnetic field
- Force proportional to strength of magnetic field
- Direction of force perpendicular to direction of wire and direction of field

**Direction of Force Depends on Directions of Current and Magnetic Field**

- Force proportional to current in wire
- Force proportional to length of wire in magnetic field
- Force proportional to strength of magnetic field
- Direction of force perpendicular to direction of wire and direction of field

**Starting Point for Force Formula**

\[ F = I L B \]

\[ [N] = [A][m][T] \]

This formula only describes magnitude, not direction.

**Experimental Observations**

- Force proportional to current in wire
- Force proportional to length of wire in magnetic field
- Force proportional to strength of magnetic field
- Force depends on angle between wire and magnetic field
- Direction of force perpendicular to direction of wire and direction of field
20.3 Force on an Electric Current in a Magnetic Field; Definition of $B$

The force on the wire depends on the current, the length of the wire, the magnetic field, and its orientation.

$$F = I L B \sin \theta$$  \hspace{1cm} \text{(20-1)}

This equation defines the magnetic field $B$.

Unit of $B$: the tesla, T. \hspace{1cm} \text{THIS IS THE SI UNIT}

$1 \text{T} = 1 \text{N/A} \cdot \text{m}$.

Another unit sometimes used: the gauss (G).

$1 \text{G} = 10^{-4} \text{T}$.

Magnetic field of earth $\sim 0.5 \text{G}$

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**Figure 20-12**

Current-carrying wire in a magnetic field

$$F = I L B \sin(\theta)$$

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**Drawing 3D Fields**

End \hspace{1cm} On \hspace{1cm} View

Field Out of Board \hspace{1cm} Field Into Board

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**Right Hand Rule**
For magnetic force on moving particle: The magnitude of the force depends on the angle between \( \vec{v} \) and \( \vec{B} \)

Magnetic Force is only due to moving charges

\[
F = IIL \sin \theta
\]

\[
|\vec{F}| = qvB \sin(\theta)
\]

\[
I = \frac{\Delta Q}{\Delta t}
\]

For \( N \) charges, each having charge \( q \)

\[
I = \frac{Nq}{L}
\]

Let \( t = \) time for charge to move distance \( L \)

\[
L = vt
\]

\[
F = \left( \frac{Nq}{L} \right) (vt)B \sin(\theta)
\]

Find force on a single charge (\( N = 1 \))

\[
F = qvB \sin(\theta)
\]

20.4 Force on Electric Charge Moving in a Magnetic Field

The force on a moving charge is related to the force on a current:

\[
F = qvB \sin \theta
\]

(20-3)

Once again, the direction is given by a right-hand rule.

20.4 Force on Electric Charge Moving in a Magnetic Field

If a charged particle is moving perpendicular to a uniform magnetic field, its path will be a circle.

The magnitude of the force depends on the angle between \( \vec{v} \) and \( \vec{B} \)

\[
|\vec{F}| = qvB \sin(\theta)
\]

The direction is given by a right-hand rule.
20.4 Force on Electric Charge Moving in a Magnetic Field

Problem solving: Magnetic fields – things to remember
1. The magnetic force is perpendicular to the magnetic field direction.
2. The right-hand rule is useful for determining directions.
3. Equations in this chapter give magnitudes only. The right-hand rule gives the direction.

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Magnetism and Quantum Physics

How do magnets work? 6:25

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Magnetism and Special Relativity

How Special Relativity Makes Magnets Work 4:18

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Magnetic Fields Can Cause A turning motion

The forces on opposite sides of a current loop will be equal and opposite. However, if the loop is held fixed but allowed to rotate, the magnetic field can cause the loop to rotate.

This leads to:
Meters and Motors

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20.10 Applications: Galvanometers, Motors, Loudspeakers

A galvanometer takes advantage of the torque on a current loop to measure current.

This is the core of an ammeter and a speedometer.
20.10 Applications: Galvanometers, Motors, Loudspeakers

An electric motor also takes advantage of the torque on a current loop, to change electrical energy to mechanical energy.

Loudspeakers use the principle that a magnet exerts a force on a current-carrying wire to convert electrical signals into mechanical vibrations, producing sound.

Summary of Chapter 20

- Magnets have north and south poles
- Like poles repel, unlike attract
- Unit of magnetic field: tesla
- Electric currents produce magnetic fields
- A magnetic field exerts a force on an electric current:

\[ F = I I B \sin \theta \]

- Magnitude of the field of a long, straight current-carrying wire:

\[ B = \frac{\mu_0 I}{2\pi r} \]

Quantum Levitation 5:08